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San Francisco Public Utilities Commission

Cryptosporidium White Paper

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Cryptosporidium White Paper

This paper summarizes relevant information and current research issues on *Cryptosporidium* relevant to its public health significance in water supplied. From this assessment, suggestions are made for actions to be taken by the San Francisco Water Department.

Background

To safeguard public health, regulations have been promulgated regarding drinking water authorized by the 1986 Amendments to the Safe Drinking Water Act. A pertinent piece of legislation is the Surface Water Treatment Rule, which was enacted by both the United States Environmental Protection Agency and the State Department of Health Services (DHS) in June 1989 and 1991, respectively. San Francisco is under a compliance order to meet this regulation by 1999. The purpose of the Safe Drinking Water Treatment Rule is to minimize microbial risk due to parasites (i.e., *Giardia*), bacteria (i.e., *Legionella*) and viruses from surface water supplies. While this rule does not place limits on *Cryptosporidium* due to lack of information, it has, however, become of great interest due to recent outbreaks in England and in North America. *Cryptosporidium* may be regulated under the Enhanced Surface Water Treatment Rule (to be promulgated in 1998); 2-log and 3-log removal requirements have been suggested.

History

Cryptosporidium was first described in 1907 by Ernest Edward Tizzer. His work was not regarded as important at the time, and half a century passed before *Cryptosporidium* became of minor interest in association with the incidence of cryptosporidiosis in turkeys. Interest in *Cryptosporidium* heightened in 1971 when *Cryptosporidium* was found to be associated with diarrhea in cows.51 In 1976, the first cases of human cryptosporidiosis were reported. After that, relatively few cases were reported until 1982, when cryptosporidiosis was associated with protracted diarrhea in patients with acquired immune deficiency syndrome (AIDS).7,16,38 This finding stimulated intense medical and veterinary interest in the epidemiology, diagnosis, treatment, and prevention of cryptosporidiosis.

The first reported human outbreak of cryptosporidiosis due to water supply occurred in Texas in 1984 concurrently with an outbreak of Norwalk virus. This was followed by the second largest North American outbreak in Carrolton, Georgia, in 1987, where over 13,000 people were affected.25 Two outbreaks of *Cryptosporidium* occurred in the United Kingdom in 1988; the larger in December 1988 affected approximately 5,000 people.39 Since this time, several smaller outbreaks have occurred in the United Kingdom.24,25 In April 1993, the largest North American outbreak affecting almost 400,000 people occurred in Milwaukee, Wisconsin.36 This outbreak has attracted much national attention and the effects of the outbreak were still experienced even a year later.30,47,55 Most water supply related incidents of *Cryptosporidium* have occurred during the spring and in filtered supplies.

The Organism

The Organism

Description

Cryptosporidium is an oval-shaped protozoan parasite found in man, mammals, birds, fish, and reptiles. *Cryptosporidium* has a complicated life cycle (Figure 1) which goes through many forms, the most relevant form being a 4 to 6 m diameter oocyst, which contains the infective sporozoites.15,18 Although the number of species of *Cryptosporidium* is open to questions, only one, *C. parvum*, appears responsible for significant human health concerns.

Cryptosporidium oocysts are resistant to adverse environmental factors and can survive for months under optimum environmental conditions.43 The released infective sporozoites do not survive well.

The Disease

In humans, cryptosporidiosis results in a self-limiting but unpleasant diarrhea in immunocompetent individuals with an incubation period of 2 to 10 days. Some of the associated symptoms include anorexia, weight loss, dehydration, abdominal cramping, and vomiting (i.e., headache, aching muscles, fever). On average, the symptoms last for 12 days with rare instances lasting as long as 4 weeks.4,7,13 In patients with depressed immunity due to disease (i.e., HIV infection, chemotherapy, etc.) or congenitally depressed immunity (e.g., hypogammaglobuinemia), similar symptoms are observed. The duration, however, can be much longer and some individuals never clear *Cryptosporidium* from their systems. In cases where suppression of the immune system cannot be reversed (e.g., by stopping immune suppressant therapy) these symptoms may persist until death.6,11,21

Prevalence

Human cryptosporidiosis has been identified on all six continents.3,5,13,52 Among people with gastrointestinal complaints, the prevalence of *Cryptosporidium* oocysts in patient's stools range from 1 to 4 percent in developed countries and up to 16 percent in developing countries. Specific North American surveys indicated similar levels. For example, in British Columbia, Canada, the prevalence was 0.6 percent, in Massachusetts it was 2.8 percent, and in South Carolina 4.3 percent. In England, *Cryptosporidium* is the fourth most common cause of diarrhea.50

In the immunocompromised population, particularly those infected with HIV, the prevalence is higher. Estimates of the percent of HIV-infected patients with cryptosporidiosis range from 1 to 2 percent up to 10 percent. Of AIDS patients with diarrhea, *Cryptosporidium* has been identified as an agent in 10 to 15 percent of the cases.6,52

Immunity

Exposure to *Cryptosporidium* does not necessarily lead to clinical disease. There is some indication that prior exposure results in protective immunity from cryptosporidiosis, though the duration of this immunity is unknown. Serological testing has found *Cryptosporidium*-associated antibodies in 25 to 35 percent of people tested in North America, indicative of a moderate level of *Cryptosporidium* exposure.52

Treatment

Over 90 antimicrobial agents have been used against *Cryptosporidium* in animals and man, but no specific effective treatment for cryptosporidiosis has yet been found.18 While this is not of great importance

effective treatment for cryptosporidiosis has yet been found.18 While this is not of great importance among immunocompetent individuals (except for days of work lost) where the infection is self-limiting, it is vital for immunosuppressed patients. Several clinical trials are currently evaluating some promising agents including letrazuril, azithromycin, paramomycin, and a hyperimmune bovine colostral immunoglobulin. The last mentioned agent shows great promise; it is being evaluated at San Francisco General Hospital.38

Transmission

Accurate identification of the modes of transmission is of critical importance in evaluating the risks associated with cryptosporidiosis.

Sources

Reservoirs for *Cryptosporidium* include mammals, birds, fish, and reptiles. Species shed by one host can infect other hosts (e.g., cattle can infect humans). Animals that can carry *Cryptosporidium* include cattle, pigs, cats, deer, guinea pigs, mice, rats, and sheep. Young animals that are most likely to develop symptomatic infections and shed high quantities of infective oocysts.

Exposure Routes

There are a variety of exposure routes. Cryptosporidiosis is normally transmitted by the fecal-oral route, when oocysts excreted by an infected animal or human are ingested by a susceptible person. A number of transmission routes exist because oocysts are capable of infecting other hosts immediately when released into the environment and after surviving in the environment for a period of time. These routes are:

n From Animals - Transmission from animals to man has been documented by veterinarians and others working closely with sheep and cows. Gulls have been shown to be carriers.49 Pet animals such as dogs and cats have also been implicated in human cases.41

n Person-to-Person - Person-to-person transmission is important. Cryptosporidiosis transmission can occur easily within families, play groups, nursery schools, day care centers, hospitals, and other institutions where precautions are not taken. Sexual transmission is also suspected, particularly in the gay community.23

n From Water - Several major outbreaks in the last 10 years have shown that cryptosporidiosis can be contracted from contaminated water. Wastewater plants are not wholly effective in removing *Cryptosporidium*.53 Recreational contact with contaminated water in reservoirs, rivers, and other waters has been documented as a transmission source. Included in this category is an incident where 17 people contracted cryptosporidiosis while at a local wave pool.32

n Airborne - Some indications exist that airborne spread of *Cryptosporidium* occurs, although these have not been well documented.

n Other - There have been a few reports of infection with *Cryptosporidium* following consumption of raw milk and raw sausages. In 1993, 160 people contracted cryptosporidiosis due to drinking contaminated apple cider at an agricultural fair in Maine.34 This has not been previously thought to be a significant route.

Infectivity

Uncertainty exists concerning the dose required to induce infection (not even considering virulence differences for different strains). While most indications suggest that the dose required to induce infection is between 1 to 100 oocysts,3,19,38 one study indicated that doses of 10,000 oocysts were not capable of inducing infections in adult monkeys. Recently, Dupont and his colleagues completed a human feeding study which determined that the dose at which 20 percent of the subjects were infected was 30 oocysts while a 40 percent infection rate of the subjects was 100 oocysts (Figure 2). From this information, Haas and Rose propose that the minimum infectious dose is 1 oocyst.24

Figure 2

Dose Response Data of DuPont

Fit to Exponential Model

The immunocompromised apparently are the most susceptible population. There is some indication that deficiencies in the immune system during pregnancy make pregnant women more susceptible to a prolonged bout of cryptosporidiosis. It is reported that when CD4 counts (CD4 counts indicate the level of T-helper cells in the immune system) are less than 180, the host will usually be unable to clear the disease.31,38 The CD4 counts for normal individuals typically are between 800 and 900.

Relative Public Health Significance

Assessing the relative public health significance of *Cryptosporidium* is complex because of the different responses between immunocompetent and immuno-compromised individuals. Sexually transmitted diseases typically account for the highest incidence of infectious diseases followed by gastrointestinal illnesses.

Major Facts

Several points frame the question of public health significance:

n The prevalence of cryptosporidiosis is between 1 and 4 percent of the total population in North America.52

n A number of waterborne disease outbreaks have been associated with *Cryptosporidium*.35

n Cryptosporidiosis is usually self-limiting, except in immunocompromised individuals.38

n Groups at risk include:

Animal handlers

Health care workers

Day care center children/employees

Consumers of contaminated water

Travelers to developing countries

Immunodeficient and immunosuppressed persons

- Congenital deficiency

- Acquired deficiency

- Immunosuppressive therapy

- Malnourished

n Incidence of cryptosporidiosis amongst AIDS patients is not well known, but is estimated to be between 1 and 10 percent.6,38 Of these infected patients, it is not known how many may die directly from cryptosporidiosis, but numbers as high as 20 percent have been speculated.52

n No therapeutic agent has been found to treat cryptosporidiosis.

n In some cases where *Cryptosporidium* has been detected, other pathogenic organisms have also been detected (e.g., *Giardia*, rotavirus).13

Other Infectious Organisms

Cryptosporidium is not the only organism which causes diarrheal symptoms.5,11,13,23,33,39 Immunocompromised individuals, particularly with those with AIDS, can be infected by a variety of other diarrhea causing organisms, including:

n Cytomegalovirus

n *Mycobacterium avium*

n *Salmonella*

n *Entomoeba histolytica*

n *Giardialamblia*

n Herpes simplex

n *Campylobacter jejuni*

n *Isopora belli*

n *Campylobacter difficile*

n *Candida*

n *Strongyloides*

n *Enterocytozoon bieneusi*

Some of these organisms (e.g., cytomegalovirus and *Isopora belli*) have been detected concurrently with

Some of these organisms (e.g., cytomegalovirus and *Isopora belli*) have been detected concurrently with *Cryptosporidium* during bouts of infectious diarrhea.11,23,33,39

Summary

Cryptosporidium is one of several agents involved in infectious diarrhea and is particularly devastating for immunocompromised individuals who are unable to clear the disease. While the incidence of reported cryptosporidiosis appears to be low, this may be underestimated due to factors such as lack of reporting by doctors and lack of diagnosis. The treatment of cryptosporidiosis has been relatively unsuccessful, although there appears to be some promise in use of a hyperimmune bovine colostrum.

Water Treatment

Occurrence in Water

Cryptosporidium is shed from infected individuals in their stools. Concentrations of infective oocysts are very high in the stools with levels on the order of one million oocysts per day being estimated. *Cryptosporidium* can be transmitted directly from person to person through the fecal-oral route. *Cryptosporidium* can also find its way into the environment and, hence, into drinking water sources.

Detection

Because the conventional indicators of microbial water quality (e.g., coliforms and heterotrophic plate counts) do not necessarily correlate with the presence or concentrations of *Cryptosporidium* and because the minimum infective dose is thought to be very low, detection of low *Cryptosporidium* concentrations is necessary. To accomplish this, methods have been developed that rely on concentrating large volumes of water (i.e., 100 to 1000 gallons) into a small pellet (ASTM Method P229). The method is detailed in the proposed Information Collection Rule. The basis of the procedure is as follows:

n *Sampling* - Water is taken from the source by pumping into a filter housing containing a polypropylene yarn cartridge filter.51 The volume of water passed through the filter is measured using a water meter.

n *Concentration* - After transport to the laboratory, the particles trapped on the filter are eluted using large volumes of detergent. The eluate is then centrifuged to concentrate and separate out particles denser than the oocysts.45,51

n *Identification* - Microscopic examination of the concentrated sample relies on actual measurement of size and the use of fluorescent antibody stains to identify the oocysts.14 A distinguishing feature of *Cryptosporidium* is the fold in the oocysts.

There are several problems with current detection methods.1,2,44,45

n The species of *Cryptosporidium* cannot be distinguished using conventional methods.

n Some of the antibodies used for detection may cross-react with other organisms (e.g., yeasts) so that enumeration of oocysts may include species (or other organisms) that are not infectious to humans.14,45

n Detection of the oocysts does not indicate whether they are viable (i.e., capable of inducing infection).

n There is no method for assessing the virulence (i.e., the severity of the disease produced) of a particular strain of *Cryptosporidium*.

strain of *Cryptosporidium*.

n Current concentration techniques result in recoveries in the range of only 20 to 70 percent with the efficiency being a function of the water matrix.45

n Variations between laboratories for identical samples can be as high as 100 percent, even with standardized procedures proposed in early 1995 for the EPA's Information Collection Rule.

There is some indication that particle counting may be a useful surrogate for assessing efficiency of *Cryptosporidium* removal by water treatment processes.

North American Source Waters

Typical geometric average concentrations for various water types have been as follows:45

n Lakes - 0.44 oocysts per liter

n Rivers - 0.43 oocysts per liter

n Springs - 0.04 oocysts per liter

n Groundwater - 0.003 oocysts per liter

In North American waters, the values of *Cryptosporidium* range from 0.002 to 5,800 oocysts per liter, depending on the source. These values will vary depending on the watershed characteristics of the water source. Concentrations of *Cryptosporidium* oocysts in source water tend to be higher than *Giardia*.2,45

North American Treated Waters

Cryptosporidium oocysts have been detected in treated waters in the western United States. These values tend to be low, averaging 0.001 oocysts per liter in filtered waters and 0.006 oocysts per liter in non-filtered waters. In waterborne outbreaks *Cryptosporidium* oocyst concentrations in the treated water were much higher than these values. For example, in the Carrolton, Georgia outbreak, treated water oocyst levels were 2.2 per liter. After the outbreak in Milwaukee, treated water oocysts levels reached 0.16 per liter. However, there is significant uncertainty as to how high the levels were during the outbreak.

Outbreaks have been more often associated with filtered waters than unfiltered waters, and usually with agricultural (particularly animal wastes) contamination of drinking water sources. In a filtration process, *Cryptosporidium* oocysts, *Giardia* cysts, other pathogens and debris are concentrated in the filters so that breakthrough of the accumulated material can increase the risk of *Cryptosporidium* infections.

Effectiveness of Water Treatment Processes

The two basic mechanisms for eliminating pathogenic organisms during water treatment are: chemical inactivation and physical removal. The former is accomplished through disinfection, and the latter through coagulation and filtration.

Disinfection

Chlorine is not effective for inactivating *Cryptosporidium* oocysts. It has been reported that oocysts

Chlorine is not effective for inactivating *Cryptosporidium* oocysts. It has been reported that oocysts exposed to undiluted household bleach (5% NaOCl) for several hours were still capable of inducing infection.48 Chlorine dioxide appears to be effective, but at doses far higher than would be reasonable in water treatment, especially in light of the concern over the chlorine dioxide by-products chlorite and chlorate.22 Ozone is effective for inactivating *Cryptosporidium* but requires Ct values 10 to 20 times greater than for *Giardia*20. Ultraviolet light is effective at inactivating *Cryptosporidium* though at very high doses.29 Ct values for various disinfectants against *Cryptosporidium* and *Giardia* are presented in Table 1.3,20,22,51 Sequential use of these disinfectants, however, results in synergestic effects.

Even though ozone appears to be effective for *Cryptosporidium* inactivation, there is a major concern regarding its use. Due to its powerful oxidizing ability, it breaks down the naturally occurring organic matter in water, causing it to become a nutrient source for bacteria. It is possible, then, that the use of ozone, while inactivating *Cryptosporidium*, could stimulate the growth of bacteria in the distribution system. Some of these bacteria may cause disease, particularly in immunocompromised individuals.

Filtration

Removal of *Cryptosporidium* by filtration is approximately 99 percent or 2 logs of reduction. Although levels as high as 99.9 percent or 3 logs of reduction have been reported. At times oocysts can be detected in filtered water; their breakthrough can be attributed to a variety of factors, including:

n Increases in source water concentrations of *Cryptosporidium*.

n Recycling filter washwater in the plant enabling concentrated slugs of *Cryptosporidium* to pass through the filters.

n Operational factors such as improper filter washing, rapid flow changes, improper coagulation, etc.

Most waterborne *Cryptosporidium* outbreaks have been associated with operational problems rather than inherent treatment deficiencies.

Regulatory Stance

The regulatory stance varies considerably. The activities of the United Kingdom Drinking Water Inspectorate, the United States Environmental Protection Agency, the California Department of Health Services, and Canadian Authorities are summarized below.

United Kingdom

Regulatory authorities in the United Kingdom have the most extensive experience with the issue because of the number of outbreaks experienced. Their stance on *Cryptosporidium* is summarized in two major documents: The Badenoch Report entitled "*Cryptosporidium in Water Supplies*" (July 1990) and the Drinking Water Inspectorate's report "*Cryptosporidium in Water Supplies: Progress With the National Research Program*" (July 1992). The basic recommendation of these reports is that water treatment plants need to optimize their practices with respect to coagulation, filtration, and recycling of filter washwater.8 The Drinking Water Inspectorate is leading an aggressive research program to address the major research needs.

EPA

Cryptosporidium was not regulated under the 1989 Surface Water Treatment Rule due to the

uncertainties surrounding *Cryptosporidium* (i.e., virulence, infective dose, inactivation, etc.). Source monitoring for *Cryptosporidium* will be required sometime in 1996 under the Information Collection Rule (ICR). Methodological difficulties with the detection method have slowed down promulgation of the ICR. If satisfactory results with the refined method are not obtained, the ICR may be delayed further into 1996. The proposed Enhanced Surface Water Treatment Rule (ESWTR)17 is in its final stages of revision prior to its formal proposal. Some significant items noted in the draft ESWTR Preamble (dated January 26, 1994) are:

n Differing pathogen densities in different waters accounts for the drive to develop site-specific treatment requirements.

n In light of current and anticipated research EPA senses that they will "soon be in better position to develop a suitable regulation for *Cryptosporidium*".

n There appears to be some conferred immunity associated with exposure to *Cryptosporidium*. A 2-log treatment requirement has been proposed as an option for sources with less than 1 oocyst per 100 liters, though there are other proposals.

n EPA recognizes that "unfiltered systems would appear to be particularly vulnerable...However, to date, filtered water supplies have been implicated in all identified waterborne *Cryptosporidium* outbreaks...(filtered) surface water may be more vulnerable to *Cryptosporidium* than unfiltered supplies with disinfection, depending on the quality of the source water..."

Great uncertainty still remains as EPA approaches a regulation. Consequently, they are soliciting input into the structuring of ESWTR. A major emphasis for unfiltered systems will be on watershed controls.

California Department of Health Services (DHS)

DHS is concerned over the status of unfiltered supplies in the state. While anticipating that *Cryptosporidium* will need to be regulated in the near future, DHS will await for EPA's action.

Centers for Disease Control and Prevention (CDC)

In September 1994, CDC convened a meeting to address concerns over waterborne cryptosporidiosis involving representatives from regulatory and public health agencies, water utilities, and advocacy groups. The focus of the workshop was to avoid unnecessary alarm (i.e., premature or unwarranted boil water advisories) and preventing waterborne outbreaks. Four workgroups addressed the special topics: surveillance systems and epidemiological study designs, public health responses, immunocompromised persons, and water sampling methods and interpretation of results. A document published in 199510 noted that there was significant uncertainty regarding waterborne cryptosporidiosis and as such recommended increased surveillance and epidemiological investigations, methods development for *Cryptosporidium* detection in drinking water, and development of task forces for providing information to the immunocompromised as well as regional population.

Canadian Authorities

There are no current regulations for *Cryptosporidium* or *Giardia,* though *Giardia* has been identified as a public health concern. The only regulatory guidance on microbial water quality is for coliform levels in the distribution system. There are no current plans to regulate *Cryptosporidium*.

Summary

Of all the regulatory agencies contacted, EPA appears to be the most aggressive in pursuing a *Cryptosporidium* regulation, but is hampered by poor analytical methods. In the wake of the Las Vegas and Milwaukee outbreaks, EPA is continuing its efforts. Other organizations, due to the meagerness of available information, have decided not to regulate *Cryptosporidium* at this time.

Current Activities of the Water Industry

A number of water agencies in North America and Europe were contacted to determine their activities with respect to *Cryptosporidium*. There appears to be much interest in assessing *Cryptosporidium* levels and optimizing treatment practices to minimize its passage into the water supply.2,3,40,42 Activities include:

n Monitoring of source and treated waters for *Cryptosporidium*,

n Optimizing coagulation practices,

n Monitoring turbidity of individual filter cells,

n Backwashing filters prior to restarting,

n Evaluating filter washwater treatment (i.e., clarification and/or disinfection),

n Setting limits for turbidity spikes occurring after filter restarts (i.e., ripening period),

n Controlling filters in a manner to avoid sudden flow changes,

n Optimizing disinfection, and

n Watershed management.

For unfiltered sources there has been a strong emphasis on watershed management,42 though some (e.g., New York City) are receiving pressure to filter.37,54 Interestingly, few recommendations have been made by the medical community for immunocompromised individuals to seek alternative water sources,38 even in Milwaukee.46,47

Individual agency activities as of December 1992 are summarized in Appendix A. References to *Cryptosporidium* concentrations are difficult to interpret due to differences in method and sample volume.

San Francisco Water Department (SFWD) Activities

The SFWD has been aggressively pursuing the issue of *Cryptosporidium* in the following manner:

n Monitoring - Preliminary monitoring for *Giardia* and *Cryptosporidium* was conducted in 1990. This has been followed by an intensive 12-month monitoring program for all sources, both treatment plants, and two distribution system reservoirs. The program has been completed, although some monitoring continues.

n Consultations - A number of meetings have taken place with DHS staff regarding *Cryptosporidium*. In

n Consultations - A number of meetings have taken place with DHS staff regarding *Cryptosporidium*. In July 1992, the SFWD met with health officials from the four Bay Area counties served by the SFWD to discuss the significance of waterborne *Cryptosporidium*. In November 1992, SFWD staff met with four water utilities to discuss their respective programs on *Cryptosporidium* (Appendix B). In January 1993, the SFWD convened a workshop with regulatory authorities (i.e., DHS and EPA), public health officials, researchers and medical experts to discuss the incidence of cryptosporidiosis, its relative public health significance, current research, and potential studies to address the major uncertainties (Appendix C). A Bay Area workshop was held in June 1995 to evaluate a disease surveillance program and to discuss risk communication issues (Appendix D). The SFWD is planning to conduct stakeholder interviews to assess public concern and attitudes towards costs of various treatment alternatives. These are scheduled to be completed in fall of 1995. In addition, San Francisco supervisor Carole Migden has formed a 17 member multi-disciplinary *Cryptosporidium* task force for the purpose of developing guidelines for public notification of immunocompromised individuals and the general public. Proposed guidelines are to be developed by October 1995.

n Treatment - The SFWD is performing an evaluation of its filtration practices at the Harry Tracy and Sunol Water Treatment Plants to optimize particulate removal. Pilot studies at Hetch Hetchy evaluated optimization techniques for *Cryptosporidium* removal. Disinfection studies were performed at the University of Arizona evaluating the influence of existing physical and treatment conditions in the SFWD Hetch Hetchy water delivery and treatment system on *Cryptosporidium*. These included pH changes (SFWD water is increased from 7 to 10), pressure drops (there are two major powerhouses on the Hetch Hetchy Aqueduct that may rupture the oocysts), and sequential addition of disinfectants. These studies indicated that *Cryptosporidium* inactivation is currently negligible, but that sequentially adding chlorine followed by chloramine is capable of inactivating *Cryptosporidium*. Results presented in late 1994 prompted the SFWD to conduct their own investigation as to inactivation with existing chlorine followed by chloramine. Results just obtained (July 1995) indicated that one disinfection scheme (a short free chlorine contact time of Hetch Hetchy water followed by pH adjustment and ammonia addition to form chloramine) achieved 1 log (or 90 percent) *Cryptosporidium* inactivation. The required ozone dose for inactivating *Cryptosporidium* in Hetch Hetchy has been determined to require a much longer reaction time than is conventionally used for ozonation. The risks of stimulating growth of opportunistic bacteria in consumer plumbing remains a concern with this option.

San Francisco Source and Treated Waters

The San Francisco Water Department has been intensively monitoring all three of its sources for *Cryptosporidium* and *Giardia* since January 1993. *Giardia* and *Cryptosporidium* have been detected in a few samples.

For monitoring, two methods have been used at different times. From January 1993 through October 1994, proposed Standard Method 9711B (without differential interferences contrast microscopy) was used. Since November 1994, the ICR method has been used. Using proposed Method 9711B, *Cryptosporidium* levels detected ranged from less than 0.1 to 0.8 oocysts per 100 liters in Hetch Hetchy water. *Cryptosporidium* was typically detected in approximately 30 percent of the samples collected.

With the ICR method, presumptive *Cryptosporidium* levels in Hetch Hetchy water ranged from 0.4 to 7 oocysts per 100 liters, approximately an order of magnitude greater than results obtained using proposed Method 9711B. Oocysts continued to be detected in about 30 percent of samples even though the median detection limit increased from 0.1 to 1 oocyst per 100 liters with the method change. The difference in results appears to be related to method changes rather than environmental changes (i.e., increased watershed contamination). See Appendix E for further discussion on method differences.

Cryptosporidium oocysts were also detected in some samples from San Antonio, Calaveras, and San Andreas Reservoirs (all of which are filtered) and in some finished waters. Three points should be noted. First, detection of oocysts in the treated water does not provide information about viability. There is a high likelihood that oocysts detected in finished waters are not viable.50 Second, due to the small number of samples it is not clear whether these were unusual occurrences (the largest fraction of positive samples were performed by a different lab and collected by different personnel two years ago when methods were less rigorously defined). Third, it is not unusual to detect oocysts in the treated water.2 In any case, the implication is clear: efforts should continue to focus on watershed management and treatment process optimization. These results are summarized in Table 2. The distribution of concentrations in Hetch Hetchy water is presented in Figure 3. Figure 4 shows that, despite a summertime increase in the number of positive samples, oocyst concentrations remain low year round. Appendix F contains a summary of *Cryptosporidium* and *Giardia* concentration seasonal trends for all of SFWD source waters.

Infectious Diseases Reported in San Francisco Area

Data from the San Francisco Public Health Department (see Figure 5) indicates that over the past 5 years the incidence of reported cryptosporidiosis cases has ranged from 38 in 1989 (when monitoring began) to 144 in 1991 corresponding to a risk of 1 in 5,000. This compares with roughly 400 giardiasis cases, 200 salmonella cases, 300 shigella cases, and 700 campylobacter cases (all of which are treatable). Most of the San Francisco *Cryptosporidium* cases are attributed to AIDS patients and are not thought to be water related. The county environmental health officers of Alameda, San Francisco, San Mateo, and Santa Clara believe that cryptosporidiosis from drinking water is not a major concern.

A preliminary epidemiological assessment was conducted by the Community Disease Control Program of the City and County of San Francisco. Five hundred and thirty three (533) cryptosporidiosis cases were segregated according to areas served by filtered and unfiltered water. The incidence of cryptosporidiosis was four times higher in the filtered area than in the unfiltered area. Even though this study was biased towards males and patients with AIDS, it did not uncover an association between unfiltered Hetch Hetchy water and cryptosporidiosis. Further work would need to be done to assess the importance of unfiltered Hetch Hetchy water. The indications from this preliminary study, however, is that there is no "smoking gun" pointing to unfiltered Hetch Hetchy water.

Table 2

Figure 3

Distribution of *Cryptosporidium* in Hetch Hetchy Water

(Presumptive Results)

Figure 4

***Cryptosporidium* Levels in Hetch Hetchy Water**

Figure 5

Infectious Disease in San Francisco

Research Needs

There are many unanswered questions concerning *Cryptosporidium* in potable waters that require investigation. The following are important to San Francisco:

n *Viability Assessment* - Some techniques have been developed in Scotland that allow viability assessment of detected oocysts. This technique is undergoing refinement9,28 and should be used by San Francisco for assessing *Cryptosporidium* viability when it is detected in its source water.

n *Method Consistency* - Methods for detecting *Cryptosporidium* in source waters are highly variable and results are not readily reproduced within the same lab or between different laboratories (see Appendix E). Developing new methods that enable more consistent and sensitive results is needed.

n *Method Specificity* - Current detection methods fail to distinguish between species thought to be responsible for human disease and those that are thought not to cause disease in humans. Method development is needed to allow that differentiation.

n *Infective Dose* - While there is some indication that the infective dose for cryptosporidiosis is very low, it is not known whether different species of *Cryptosporidium* have different infectivity (though it seems likely). No information is available on the infectious dose for an immunocompetent person compared to an immunocompromised person. However, several ongoing studies may shed light on these questions. Feeding studies in Scotland with infection-free lambs suggest that doses as low as 5 oocysts per liter can cause 100 percent infection. A primate study in Kenya will soon be finalized. Initial results have been ambiguous since low oocyst doses induced disease in some primates while higher doses failed to produce any illness in other primates (maybe due to acquired immunity). A human feeding study in Texas evaluating the infectivity of various *Cryptosporidium* oocyst doses found 20 percent of the subjects were infected at the lowest dose (30 oocysts). A joint University of California at Davis and University of California at San Francisco study will evaluate the infective oocyst dose for immunocompromised primates to provide information on the minimum infective dose for immunocompromised populations.

n *Relative Exposure* - It is unclear how much of the cryptosporidiosis risk can be attributed to drinking water. Work is vitally needed that distinguishes the water contribution to cryptosporidiosis from other sources. This will enable better risk management and more efficient resource allocation.

n *Communication of Uncertainty* - Issues associated with detection, species differentiation, viability, infectivity, host susceptibility, compel the uncertainty associated with cryptosporidiosis risk in drinking water. Better methods are needed for quantitatively characterizing this uncertainty and communicating it in a manner that is comprehensible to the public and aids them in making their own personal risk management decisions.

n *Chemical Inactivation* - Further work needs to be done to evaluate the impacts of chlorine on environmentally-stressed oocysts which may be more susceptible to chlorine inactivation than fresh oocysts. The impact of sequencing disinfectants (e.g., chlorine followed by chloramine) needs to be evaluated further so as to refine the available alternatives for the SFWD with regards to disinfection by-products.

n *Filtration* - While some preliminary work has been conducted on the removal of *Cryptosporidium* in water treatment processes, more is needed on the influence of filter media and filtration rates. An assessment of the importance of increased parasite loading during the backwash water operations such as recycling, and flow rate changes needs to be made. Work on *Cryptosporidium* removal is being

recycling, and flow rate changes needs to be made. Work on *Cryptosporidium* removal is being completed under the auspices of AWWARF and by the British Drinking Water Inspectorate.

Current Action Plan

The SFWD action plan is focused on providing information that will aid in the assessment and control of the risks associated with *Cryptosporidium*.

n *Monitoring* - SFWD will continue its monitoring program for its major sources and start to monitor treated water samples in addition to the existing distribution system locations. The sample volumes have been increased to lower the detection limits.

n *Treatment Process Evaluation* - The two SFWD filtration plants already conform to the recommendations of the Badenoch report and the Surface Water Treatment Rule. Nevertheless, an evaluation of operating practices (e.g., increasing plant flows, treating high turbidity water, washwater handling, etc.) is planned to determine how plant operations can adapt to adverse conditions and protect against parasite breakthrough.

n *Watershed Sanitary Survey* - A comprehensive watershed survey has been conducted which (1) identifies the origin of the *Cryptosporidium* oocysts (i.e., sampling major tributaries into reservoirs, camping areas, septic tanks, stables, etc.), (2) evaluates the transport and fate of the oocysts, and (3) determines the degree to which the oocyst sources can be controlled. The recommendations for watershed management are under development.

n *Risk Communication* - Both the San Francisco *Cryptosporidium* Task Force and the Bay Area water utility risk communication workgroup are developing a plan for presenting information on risks to affected parties.

These four activities are planned for completion by the end of 1996.

Possible Future Studies

In addition to the studies currently being conducted by the SFWD, the following studies will also be valuable:

n *Exposure Assessment* - If a current research project examining the contributions of water to the degree of exposure of a population proves successful, it would be advisable for San Francisco to conduct similar studies to ascertain the contribution of exposure to unfiltered water presents to the various affected populations. This may be the key piece of data needed to determine the relative significance of water towards the cryptosporidiosis cases.

n *Continue to Develop Baseline Data* - Information on gastrointestinal illness rate (perhaps supplemented with selective stool monitoring) from San Francisco area hospitals would establish a baseline for any treatment changes and policy decisions.

n *Improved Sample Method Development* - In light of the importance of *Cryptosporidium* and the SFWD's current unfiltered status, it may be prudent to join in efforts to further development of *Cryptosporidium* detection methods.

n *Assess Willingness to Pay* - Since some populations are more impacted than others, it may aid policymakers to quantify the amount various individuals are willing to pay for different treatment

policymakers to quantify the amount various individuals are willing to pay for different treatment improvements (e.g., ozonation, filtration, and point of use devices). Such determinations need to use the rigorous methods developed in survey research.

n *Molecular Epidemiological Studies* - Using recently developed methods, it should be possible to type and subtype *Cryptosporidium parvum* isolates. This will allow matching of the organism shed by the infected person and the source of the organism. To address the waterborne route, SFWD needs to start collecting and storing water samples until a case of cryptosporidiosis is reported. Once the organism from the infected person is isolated and typed, an attempt could be made to match this to an organism found in the stored water samples. If a positive match is made, this would implicate the water route. If the organism matched that from a pet, a member of a family, etc., then these would be the suspected routes of infection. Such a study would provide definitive answers to whether there is a link between the drinking water and cryptosporidiosis.

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